



THE UNIVERSITY *of*  
NEW ORLEANS

## **INVITATION FOR BID**

**BID NAME AND NUMBER:  
BTB2867 AMMONIA ENGINE DIGITAL TWIN**

**BID OPENING TIME AND DATE:  
April 8, 2025@2pm**

**BUYER:  
Troy A Bacino  
TABACINO@uno.edu**

**RETURN ALL BIDS TO THE FOLLOWING ADDRESS:**

**Purchasing Office  
Administration Annex 1004G  
University of New Orleans  
2000 Lakeshore Drive  
New Orleans, Louisiana 70148  
Phone: (504) 280-6214  
Fax: (504) 280-6297**

## **General Instructions to Bidders**

### **1 Invitation to Bid**

Bids for the following items and/or services specified are hereby solicited, and will be received by the Purchasing Office until the stated bid opening time and date and then publicly opened.

### **2 Authority to Sign**

Bids must be signed by a person authorized to bind the vendor. In accordance with R. S. 39:1594(C)(4), the person signing the bid must be: 1) A current corporate officer, partnership member or other individual specifically authorized to submit bids as evidenced in appropriate records on file with the secretary of State; or 2) An individual authorized to bind the vendor, as evidenced by a corporate resolution, certificate, or affidavit; or 3) other documents indicating authority which are acceptable to the University.

### **3 Read Solicitation**

Read the entire solicitation, including all terms, conditions, and specifications.

### **4 Corrections**

All bids should be returned on the forms furnished and must be typed or written in ink. Any corrections or erasures must be initialed by the bidder.

### **5 Delivery of Bids**

Bids may be submitted in person or by mail. The mailing address is listed on the cover sheet.

Bids delivered in person or by mail should be placed in a sealed envelope and marked with the bid name and number, the bid opening time and date, and the name and address of the bidder. The same information should be affixed to any additional materials sent as a part of the bid submission.

### **6 Bid Alterations**

Alterations to bids will be accepted provided both the bid and alterations have been received in the Purchasing Office prior to bid opening time and date.

### **7 Late Bids**

Late bids will not be accepted and will be returned unopened. Each bidder is solely responsible for the timely delivery of its bid. The University will not be responsible for any delay in the delivery of bids.

### **8 Delivery/Freight Charges**

Bid prices will include all delivery/freight charges paid by the vendor, F.O.B., UNO, inside delivery, New Orleans, La, unless otherwise stated in the specifications. Any invoiced delivery charges not quoted and itemized on the UNO purchase order are subject to rejection and non-payment.

### **9 Taxes**

Vendor is responsible for including all applicable taxes in the bid price. The University

of New Orleans is exempt from all Louisiana state and local sales and use taxes. By accepting an award, all firms acknowledge their responsibility for the payment of all taxes duly assessed by the State of Louisiana and its political subdivisions for which they are liable.

### **10 Payment**

Assuming there is no prompt payment discount provision, payment will be made within thirty (30) days from receipt of products in satisfactory condition, or within thirty (30) days from date of invoice, whichever is later. Delinquent payment penalties are governed by L.R.S. 39:1695. Vendor penalties to the contrary shall be null and void, shall have no legal force, and shall not be recognized by the University in any dispute.

### **11 Acceptance**

Only the issue of a purchase order or a signed acceptance of a proposal constitutes acceptance on the part of the University.

### **Bid Signature**

By signing this bid, the bidder certifies compliance with all general instructions to bidders, terms, conditions, and specifications, and further certifies that this bid is made without collusion or fraud.

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Bidder (Company Name)

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Mailing Address

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Authorized Signature

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City, State, Zip Code

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Printed Name

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Phone Number

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Title

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Fax Number

---

E-Mail Address

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Federal Tax ID #

## **Standard Terms and Conditions**

These standard terms and conditions apply to all UNO solicitations, unless otherwise specifically amended and provided for in the special terms and conditions, specifications, or other solicitation documents. In the event of a conflict between the General Instructions to Bidders or Standard Terms & Conditions and the Special Terms & Conditions, the Special Terms & Conditions shall govern.

### **Auditors**

Bidders agrees that the Legislative Auditor of the State of Louisiana and/or the Office of the Governor, Division of Administration auditors and/or the University's auditors will have the option of auditing all accounts of the Bidder which relate to this purchase.

### **Award**

Award will be made to the lowest responsible and responsive bidder. The University reserves the right to award the items, separately, grouped, or on an all-or-none basis, and to reject any or all bids and to waive any informalities including technicalities in specifications that would preclude competition.

All solicitation specifications, terms, and conditions will be made part of any subsequent award as if fully reproduced and included therein, unless specifically amended in the formal contract.

### **Bidder Inquiries**

If a bidder is in doubt as to the meaning of any part of a solicitation, bidder may submit a written request for interpretation to the Buyer of Record. Requests must be received in the Purchasing Office no later than April 1, 2025 prior to the opening of bids. Any interpretation of the documents will be made by Addendum only, issued by the Purchasing Office, and a copy of such Addendum will be sent to all known bidders. The University will not be responsible for any other explanation of the documents.

### **Contrary Terms and Conditions**

Submittal of any terms and conditions contrary to those contained within this solicitation may cause your bid to be rejected. By signing this bid, vendor agrees that any terms and conditions which may be included in their bid are nullified.

### **Equal Employment Opportunity Compliance**

By submitting and signing this bid, vendor agrees to abide by the requirements of the following as applicable: Title VI and VII of the Civil rights Act of 1964, as amended by the Equal Opportunity Act of 1972, Executive Order 11246, Rehabilitation Act of 1973, as amended; the Vietnam Era Veteran's Readjustment Assistance Act of 1974; Title IX of the Education Amendments of 1972; the Age Act of 1975; the Americans with Disabilities Act of 1990. Vendor agrees not to

discriminate, and to render services without regard to race, color, religion, sex, age, national origin, veteran status, political affiliation, handicap, disability, or other non-merit factor. Failure to comply shall be grounds for termination of any contract entered into as a result of this solicitation.

#### Equivalency

Any manufacturer's names, trade names, brand names, or catalog numbers used in the specifications are for the purpose of describing and establishing general quality levels. Such references are not intended to be restrictive. Bids will be considered for any brand that meets or exceeds the quality of the specifications listed for any item. Bidder must state the brand/model he or she is bidding on each item. Bids not specifying brand and model number will be considered as offering the exact product specified in the solicitation.

It will be the sole responsibility of the Bidder to prove equivalency. Bidder will submit with the bid all illustrations, descriptive literature, and specifications necessary to determine equivalency. Failure to do so may eliminate the bid from consideration. The decision of the University as to equivalency will be final.

#### Governing Law

This purchase shall be construed in accordance with and governed by the laws of the State of Louisiana.

#### Louisiana Preference

A preference will be given to materials, supplies, and provision produced, manufactured, assembled, grown, or harvested in Louisiana, quality being equal to articles offered by competitors outside of the state. However, it will be the bidder's sole responsibility to indicate on his bid response which items were (or would be) produced, manufactured, assembled, grown, or harvested in Louisiana. Bidder must be able to provide satisfactory evidence to support preference claim if requested by the University. The enclosed Louisiana Preferences **must** be returned as a part of this bid.

#### Legislators Prohibited

According to LAS-R.S. 42:113(D)) the University is prohibited from entering into any contract or subcontract with a legislator or person who has been certified by the Secretary of State as elected to the Legislature or spouse of a legislator, or any corporation, partnership, or other legal entity in which the Legislator or his/her spouse owns an interest, except publicly traded corporations. Each bidder **must** return the enclosed Disclosure Form as a part of his bid.

#### New Products

All products are to be new, current model, and of best quality as measured by accepted standards of the trade. No remanufactured, demonstrator, used, or irregular products will be considered for purchase unless otherwise specified.

### Warranty

The manufacturer's standard published warranty and provision will apply, unless more stringent warranties are otherwise required by UNO and specified in the solicitation. In such cases, the bidder and/or manufacturer will honor the specified warranty requirements, and bid prices will include any premium costs of such coverage.

### DISCLOSURE FORM

EACH BIDDER IS TO DISCLOSE THE FOLLOWING INFORMATION BY ANSWERING YES OR NO TO THE FOLLOWING QUESTIONS:

1. Is the bidder a legislator or person who has been certified by the Secretary of State as elected to the Legislature? \_\_\_\_\_
2. Is the bidder a spouse of a legislator? \_\_\_\_\_
3. If the bidder is a corporation, partnership, or other legal entity, does a legislator or his spouse own any interest in that corporation, partnership or other legal entity? \_\_\_\_\_
4. If the bidder is a corporation, is it a publicly traded corporation? \_\_\_\_\_

### LOUISIANA PREFERENCES

FAILURE TO SPECIFY BELOW INFORMATION **WILL** CAUSE ELIMINATION FROM PREFERENCE.

Preferences shall not apply to service contracts.

In accordance with the Louisiana Revised Statutes 39:1595, a preference of 10% may be allowed for products produced, manufactured, grown or assembled in Louisiana of equal quality.

Do you claim this preference? YES \_\_\_\_\_ NO \_\_\_\_\_

Specify Item Numbers:

\_\_\_\_\_

Specify location within Louisiana where this product is produced, manufactured, grown or assembled:

\_\_\_\_\_

Do you have a Louisiana Business workforce? YES \_\_\_\_\_ NO \_\_\_\_\_

If so do you certify that at least fifty percent (50%) of your Louisiana business workforce is comprised of Louisiana residents?

YES \_\_\_\_\_ NO \_\_\_\_\_

### **Special Terms and Conditions**

1. All items delivered shall be subject to inspection as to grade and/or quality. If any item is inspected and fails to meet the specifications, the delivery already made will be held for the Vendor's disposition or returned to the Vendor via Freight Collect. If the Vendor fails to make satisfactory replacement within a reasonable time as determined by the University, the University reserves the right to cancel the item and to purchase it elsewhere.
2. If bidding other than the specified brand/model, a sample must be submitted with the bid.
3. Discounts for less than 1% and for less than thirty (30) days will not be considered in making awards.
4. Site Visit: In order to ascertain the true scope of the services requested, all bidders are urged and expected to inspect the site where services will be performed. Arrangements to do so may be made by contacting the buyer. Failure to inspect the site will **not** constitute grounds for a claim after contract award.
5. NOTE: If, upon visiting site, Vendor finds conditions that disagree with the physical layout as described in this bid, or other features of the specifications that appear to be in error, vendor shall notify the buyer immediately.
6. It shall be specifically agreed and understood that the Bidders may attend the Bid opening. They shall, whenever any award is considered, furnish specific samples for examination upon request by the University. It shall also be specifically agreed and understood that the decision of the University shall be final.
7. The University reserves the right to cancel this contract upon thirty (30) days written notice for failure of the Vendor to deliver on time, for delivery of unsatisfactory merchandise, or for any unsatisfactory performance by the Vendor as determined by the University.
8. This agreement may be terminated by either party with \_\_\_\_\_60\_\_\_\_\_ days advance notice in writing.
9. Successful bidder will furnish written factory instructions for the operation and maintenance of the equipment purchased.



10. Successful bidder will furnish a representative to demonstrate the operation and maintenance of the equipment.
11. Delivery Schedule: All Bidders are put on notice that the items listed on this proposal are to be delivered after the date of completion of the facilities, unless a prior date is so specified in the bid. Delivery requirements shown on this bid are necessarily approximate due to the uncertainty of the firm completion date of construction of the facilities. After issuance of the purchase order, the University will endeavor to ascertain a firm delivery date in each instance so as to avoid creating a hardship of the Vendor. In any event, no deliveries will be made without prior approval of the University.
12. In case of default by the Vendor, the University reserves the right to purchase any or all items in default on the open market, charging Vendor with any excessive costs. Should such charge(s) be assessed, no subsequent bids of the defaulting Vendor will be considered until the assessed charge(s) have been satisfied.
13. The successful bidder will be required to assume responsibility for all services and/or products offered in his/her bid whether or not he/she produces them. Further, the University of New Orleans will consider the selected bidder to be the sole point of contact with regard to contractual matters, including payment of any and all charges resulting from the contract.
14. List of distributors: The Vendor signing the bid shall be designated as the Prime Vendor on any contract/agreement resulting from this bid. If additional Vendors are authorized to receive orders for items covered under this proposal, the Vendor must submit, with bid, a list of those additional authorized distributors.
15. Delivery is of the essence and the University reserves the right to award to that Vendor providing the earliest delivery date. The University also reserves the right to reject any Vendor who cannot make delivery within \_\_\_\_\_ calendar days from the date of award.  
State firm delivery date here:\_\_\_\_\_
16. Vendors are advised that all hazardous products must be accompanied by a "Hazardous Materials Data Sheet". This sheet must also include suggested antidotes for ingestion and other contact.
17. Award to be made on an all-or-none basis.
18. All equipment must be new and delivered F.O.B. University of New Orleans, inside delivery.

19. All hardware and software must be new and delivered, F.O.B. University of New Orleans, inside delivery.
20. This is not a proprietary specification. Other manufacturer and model will be considered.
21. Fiscal Funding: The continuation of any agreement entered into as a result of this bid past the current fiscal year is contingent upon the appropriation of funds to fulfill the requirements of the contract by the legislature. If the legislature fails to appropriate sufficient monies to provide for the continuation of the contract, or if such appropriation is reduced by the veto of the Governor or by any means provided in the appropriations act to prevent the total appropriation for the year from exceeding revenues for that year, or for any other lawful purpose, and the effect of such reduction is to provide insufficient monies for the continuation of the contract, the contract shall terminate on the date of the beginning of the first fiscal year for which funds are not appropriated. Estimated budget \$1,050,000.00.
22. Piggyback: Other Louisiana Governmental Agencies may purchase at the same terms and conditions if agreed upon by awarded bidder.
23. FEDERAL CLAUSES.  
IF APPLICABLE ANTI-KICKBACK CLAUSE THE CONTRACTOR HEREBY AGREES TO ADHERE TO THE MANDATE DICTATED BY THE COPELAND "ANTI-KICKBACK" ACT WHICH PROVIDES THAT EACH CONTRACTOR OR SUBGRANTEE SHALL BE PROHIBITED FROM INDUCING, BY ANY MEANS, ANY PERSON EMPLOYED IN THE COMPLETION OF WORK, TO GIVE UP ANY PART OF THE COMPENSATION TO WHICH HE IS OTHERWISE ENTITLED.

#### CLEAN AIR ACT

THE CONTRACTOR HEREBY AGREES TO ADHERE TO THE PROVISIONS WHICH REQUIRE COMPLIANCE WITH ALL APPLICABLE STANDARDS, ORDERS OR REQUIREMENTS ISSUED UNDER SECTION 306 OF THE CLEAN AIR ACT WHICH PROHIBITS THE USE UNDER NON-EXEMPT FEDERAL CONTRACTS, GRANTS OR LOANS OF FACILITIES INCLUDED ON THE EPA LIST OF VIOLATING FACILITIES.

#### ENERGY POLICY AND CONSERVATION ACT

THE CONTRACTOR HEREBY RECOGNIZES THE MANDATORY STANDARDS AND POLICIES RELATING TO ENERGY EFFICIENCY WHICH ARE CONTAINED IN THE STATE ENERGY CONSERVATION PLAN ISSUED IN COMPLIANCE WITH THE ENERGY POLICY AND CONSERVATION ACT (P.L. 94-163).

#### CLEAN WATER ACT

THE CONTRACTOR HEREBY AGREES TO ADHERE TO THE PROVISIONS WHICH REQUIRE COMPLIANCE WITH ALL APPLICABLE STANDARDS, ORDERS OR REQUIREMENTS ISSUED UNDER SECTION 508 OF THE CLEAN WATER ACT WHICH PROHIBITS THE USE UNDER NON-EXEMPT FEDERAL CONTRACTS, GRANTS OR LOANS OF FACILITIES INCLUDED ON THE EPA LIST OF VIOLATING FACILITIES.

#### ANTI-LOBBYING AND DEBARMENT ACT

THE CONTRACTOR WILL BE EXPECTED TO COMPLY WITH FEDERAL STATUTES IN THE ANTI-LOBBYING ACT AND THE DEBARMENT ACT.

#### 44. PROHIBITION OF DISCRIMINATORY BOYCOTTS OF ISRAEL IN

ACCORDANCE WITH LA R.S. 39:1602.1.

THE FOLLOWING APPLIES TO ANY BID WITH A VALUE OF \$100,000 OR MORE AND TO VENDORS WITH FIVE OR MORE EMPLOYEES: BY SUBMITTING A RESPONSE TO THIS SOLICITATION, THE BIDDER OR PROPOSER CERTIFIES AND AGREES THAT THE FOLLOWING INFORMATION IS CORRECT: IN PREPARING ITS RESPONSE, THE BIDDER OR PROPOSER HAS CONSIDERED ALL PROPOSALS SUBMITTED FROM QUALIFIED, POTENTIAL SUBCONTRACTORS AND SUPPLIERS, AND HAS NOT, IN THE SOLICITATION, SELECTION, OR COMMERCIAL TREATMENT OF ANY SUBCONTRACTOR OR SUPPLIER, REFUSED TO TRANSACT OR TERMINATED BUSINESS ACTIVITIES, OR TAKEN OTHER ACTIONS INTENDED TO LIMIT COMMERCIAL RELATIONS, WITH A PERSON OR ENTITY THAT IS ENGAGING IN COMMERCIAL TRANSACTIONS IN ISRAEL OR ISRAEL-CONTROLLED TERRITORIES, WITH THE SPECIFIC INTENT TO ACCOMPLISH A BOYCOTT OR DIVESTMENT OF ISRAEL. THE BIDDER HAS ALSO NOT RETALIATED AGAINST ANY PERSON OR OTHER ENTITY FOR REPORTING SUCH REFUSAL, TERMINATION, OR COMMERCIALLY LIMITING ACTIONS. THE STATE RESERVES THE RIGHT TO REJECT THE RESPONSE OF THE BIDDER OR PROPOSER IF THIS CERTIFICATION IS SUBSEQUENTLY DETERMINED TO BE FALSE, AND TO TERMINATE ANY CONTRACT AWARDED BASED ON SUCH A FALSE RESPONSE.

#### 45. CERTIFICATION OF NO FEDERAL SUSPENSION OR DEBARMENT. BY

SIGNING AND SUBMITTING ANY BID FOR \$25,000 OR MORE, THE BIDDER CERTIFIES THAT THEIR COMPANY, ANY SUBCONTRACTORS, OR PRINCIPALS ARE NOT SUSPENDED OR DEBARRED BY THE GENERAL SERVICES ADMINISTRATION (GSA) IN ACCORDANCE WITH THE REQUIREMENTS IN "AUDIT REQUIREMENTS IN SUBPART F OF THE OFFICE OF MANAGEMENT AND BUDGET'S UNIFORM ADMINISTRATIVE REQUIREMENTS, COST PRINCIPLES, AND AUDIT REQUIREMENTS FOR FEDERAL AWARDS" (FORMERLY OMB CIRCULAR A-133).

A LIST OF PARTIES WHO HAVE BEEN SUSPENDED OR DEBARRED CAN BE VIEWED VIA THE INTERNET AT [HTTPS://WWW.SAM.GOV](https://www.sam.gov).

#### 46. IN ACCORDANCE WITH LOUISIANA LAW, ALL CORPORATIONS (SEE LA R.S.

12:262.1) AND LIMITED LIABILITY COMPANIES (SEE LA R.S. 12:1308.2) MUST BE REGISTERED AND IN GOOD STANDING WITH THE LOUISIANA SECRETARY OF STATE IN ORDER TO HOLD A PURCHASE ORDER AND/OR CONTRACT OVER \$25,000.

## **SPECIFICATIONS FOR AMMONIA ENGINE.**

UNO wants to acquire is a digital twin of a prototype ammonia engine, not an actual physical engine. A digital twin needs a physical twin; in our case the physical twin will be a prototype engine in a testing facility outfitted with a dynamometer to assess engine performance among other things. The digital twin we will get is a coupled hardware-software system that will follow the evolution and behavior of its physical twin; this will be achieved by non-supervised training and adaptation employing among other AI/ML methods. The plan is to have the digital twin system secured in Rm EN-608 (Eng Bldg. 6<sup>th</sup> floor); the room is almost ready to accept the system.

### **H2theFuture – Ammonia Engine Digital Twin**

The purpose of this project is the realization of a digital twin system of an ammonia-fueled marine propulsion engine prototype and the build-up of a demonstrator for this technology. The project objectives are:

1. System concept and use case definition, including:
  - A. Identification of use cases and of potential subsystems comprising the engine digital twin model
  - B. Investigation and definition of suitable neural network architecture for the engine model including important subsystems
2. Development of a neural network digital twin model based on single cylinder engine data
  - A. Data set creation via combined approach of test and simulation data
  - B. Digital Twin model building
  - C. Evaluation of the performance of the digital twin with respect to measurement data
3. Demonstrator build up
  - A. Definition of HW requirements based on selected use cases
  - B. Component selection for machine learning platform
  - C. Definition of software architecture
  - D. Implementation: Build up and HW/SW testing

## E. Demonstration of Use Cases

### **OVERALL DELIVERABLES BY ENGINE COMPONENT**

- (1) In-cylinder processes incl. but not limited to injection, ignition/combustion, compression, expansion etc.
- (2) Manifolds incl. Intake/scavenging air receiver, exhaust etc.
- (3) (Super/) Turbocharging system incl. Compressor(s) and turbine(s), air blowers etc.

### **OVERALL DELIVERABLES BY DISCIPLINE**

- (1) Thermofluids modelling, including ammonia combustion kinetics
- (2) Engine thermodynamic modelling
- (3) meta-models, i.e., methods and techniques of data fusion for model calibration, tuning, recalibration etc. These are typically either statistical or AI/ML based.
- (4) Demonstrator Build-up (hardware (HW) selection, validation)

### **DETAILED TASK LIST AND DELIVERABLE(S) PER TASK**

TASK	DELIVERABLE
	To customer (UNO) if pink-highlighted
Status quo analysis on engine dt model parameters/inputs  I) review documents on engine components, thermodynamics, combustion processes, and control systems related to engine manufacturer sce  Ii) identification of key subsystems and their interactions within the engine system. Internal discussions with engine manufacturer engine performance experts and definition of related engine dt model parameters	System concept definition of engine (sub)system incl. Overview of fundamental system quantities, with a focus on engine manufacturer's single cylinder engine (sce)
Use case definition and subsystem identification  I) use case definition together with engine manufacturer subject matter experts and research partners  Ii) based on the selected use cases definition of the required subsystems. Document the subsystems, their functions, and their interactions within the overall engine system.	Defined use case(s) and subsystems
Input/output signal determination (state, phase variables)  I) identify the required input/output signals by reviewing the project objectives (use case requirements, subsystems) and performance metrics  Ii) internal sanity check: consult with domain experts to validate the selected input/output signals and ensure their relevance	Necessary input/output signals (incl. granularity, computational speed, synchronization, etc.)

<p>lii) review/cross-check of system concept (defined in a1)</p> <p>lv) document the input/output signals, their ranges, and their potential sources (e.g., sensors, simulations).</p>	
<p>Neural network architecture</p> <p>I) review literature on latest neural network architectures used for similar applications, such as system modelling and control.</p> <p>li) investigate and test architectures based on engine manufacturer dt models, like feedforward neural networks, convolutional neural networks, and recurrent neural networks.</p> <p>lii) analyze the strengths and limitations of different architectures in terms of accuracy, complexity, and computational requirements and their suitability for each of the selected use cases.</p> <p>lv) align with project partners and select final nn architecture</p>	<p>Defined suitable neural network (NN) architecture for selected use cases</p>
<p>Simulations of ammonia combustion in air using the (initially) selected chemical kinetics ammonia combustion mechanisms in prototype problems: (i) ignition of homogeneous mixtures, (ii) combustion at psr conditions, (iii) premixed laminar flame. Here, stoichiometries and conditions representative of the experimental two-stroke ammonia engine of engine manufacturer will be used. Based on the chemical kinetics results, one (final) mechanism will be selected. Software tool: chemkin code.</p>	<p>Selection of the proper kinetics scheme for accurate emission predictions</p>
<p>Use of the selected chemical kinetic mechanism for defining an operational grid for ammonia combustion control. This operational grid can be also considered in the definition of cases that will be used to develop the engine neural network (digital twin). Software tool: chemkin code.</p>	<p>Definition of an operational grid for ammonia combustion control</p>
<p>Development of a thermodynamic model of the experimental two-stroke ammonia engine of engine manufacturer. The model will include the system auxiliaries, based on input by engine manufacturer. Combustion simulation will include the final (reduced) kinetic mechanism selected based on the present chemical kinetics studies. Testing and adaptation of the thermodynamic engine model developed against experimental data by engine manufacturer, in particular: pressure and rate of heat release traces, emission concentrations, etc. Software tool: gt-power code.</p>	<p>GT-Power model of the SCE incl. airpath and simplified combustion model excluding Engine manufacturer's proprietary combustion model (i.e. either a mapped burn-rate approach or a semi-empirical Wiebe combustion model will be used instead)</p>
<p>Integration of doe data for enhancement of dt model</p> <p>Use of the adapted thermodynamic model to generate extensive data which will be used in the development and training of the engine neural network (digital twin):</p> <p>I) identify potential sources of doe data, including previous simulations and experimental results.</p> <p>li) determine how doe data can be used to enhance</p>	<p>Simulation Design of Experiments (DoE) data from different numerical simulations</p>

the neural network model, such as by providing training data or validating model predictions.

iii) collaborate with simulation experts to integrate doe data effectively into the modelling process.

#### Dataset creation

i) data collection: gather all relevant data from various sources, including experimental data, simulation results, and any available doe data.

ii) data cleaning: identify and correct errors in the dataset, handle missing or inconsistent data, remove duplicates, and manage outliers.

iii) data preprocessing: normalize, scale, and transform the data to ensure it is in a suitable format for training the neural network. This may include feature selection, dimensionality reduction, and data augmentation techniques.

iv) dataset splitting: divide the dataset into training, validation, and test sets to ensure robust model evaluation. A common split is 60% for training, 20% for validation, and 20% for testing.

Compiled and preprocessed data for training and evaluating of the neural network model.

#### Digital twin model building

i) model architecture selection: choose an appropriate neural network architecture based on the literature review and project requirements. Consider architectures like feedforward neural networks, convolutional neural networks, or recurrent neural networks.

ii) hyperparameter tuning: optimize the hyperparameters of the neural network, such as the number of layers, number of neurons per layer, learning rate, batch size, and activation functions. Techniques like grid search, random search, and bayesian optimization can be used for this purpose.

iii) model training: train the neural network using the training dataset. Implement techniques like early stopping and dropout to prevent overfitting and improve generalization.

Trained artificial neural network representing the digital twin of Engine manufacturer's single cylinder engine

#### Digital twin model evaluation

i) performance metrics: define and calculate relevant performance metrics such as accuracy, precision, recall, f1 score, mean squared error (mse), and root mean squared error (rmse), depending on the type of problem (classification or regression).

ii) validation and testing: use the validation set to tune the model and the test set to evaluate its final performance. Ensure that the model generalizes well to unseen data.

iii) error analysis: analyze the errors made by the model to identify potential areas for improvement. This may involve examining misclassified instances or high-error predictions.

Evaluation report of the performance of the trained neural network model

Overall assessment and final adaptation of chemical kinetics - thermodynamic simulations and initial form of engine neural network in terms of pollutant (nox)

Revised thermodynamic engine model

and ghg (n<sub>2</sub>o) emissions at marine engine conditions against experimental data of engine manufacturer. Final adaptations of thermodynamic model. Software tool: gt-power code.

#### Demonstrator build up

I) definition of hw requirements based on selected use cases: analyze hardware requirements for the defined model architecture to meet the desired performance and consider necessary interfaces for the hardware

li) component selection for machine learning platform: check availability of hardware components, screen existing off-the-shelf solutions, select components based on availability, performance and compatibility, order components

lii) definition of software architecture: define interfaces used in operation and software that will be used to support mlops

lv) implementation: build the computer from ordered hardware, implement selected software packages, perform hardware and software test, implement first model on the system and test interfaces and performance of the system.

v) demonstration of use cases: implement, run and post-process predefined scenarios

#### Verified Demonstrator

### Measurement Data

Measurement data from a single cylinder ammonia engine are required to successfully conduct the project. Engine manufacturers can provide test data for the sake of thermodynamic modeling and the build-up of the digital twin (objective 2). It is understood that the data will be solely shared for the purpose of this project (according to signed NDAs), i.e. thermodynamic model development and digital twin creation, and is beyond that not part of the project deliverables.

The measurement data will comprise of

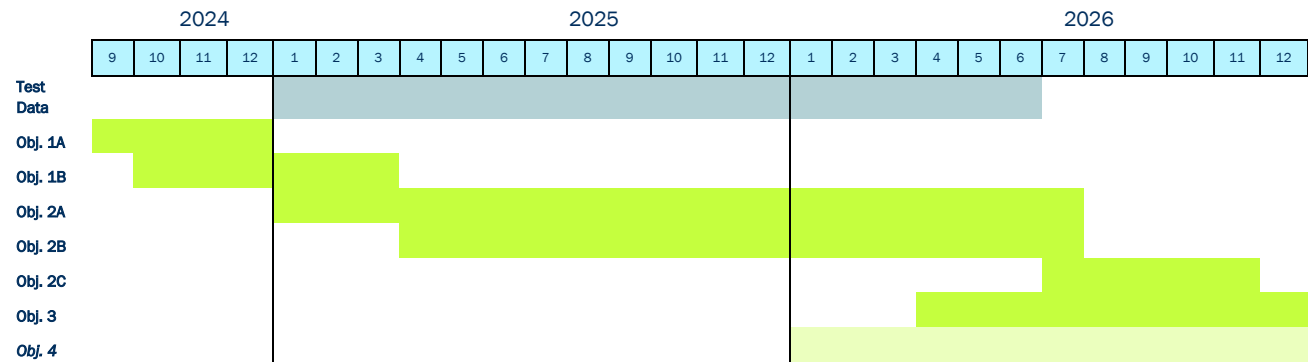
1. Test data from spray combustion chamber)
2. Thermodynamic data (in-cylinder pressure, air path pressure/temperatures, etc.) of the single cylinder test engine covering the typical operational load range of a marine engine.

The Spray Combustion Chamber data is already available and can be shared from early 2025. The measurement data from the single cylinder engine is yet to be collected.



Project Delivery and Cost

The timeline of the project is planned as follows:



Total Project Cost [USD]	
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Bid item cost \$\_\_\_\_\_